Living in a Stochastic World and Managing Complex Risks

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Abstract

In this paper, we review the concept of risk, its evolution in history and the big changes we experienced in the last 50 years. We conclude that peak risks are growing and the need for risk management is becoming a societal demand. Two phenomena are identified to render risks more complex, increasing interconnectedness of the world and faster time scale whereby actors have little time to adapt. We conclude in showing the complementary between qualitative and quantitative risk management.

Keywords: complexity, crisis, extreme risk, fertility, life expectancy, resilience, risk management, (industrial, financial) risk, scientific approach, societal demand, uncertainty, urbanization

1. Risk is not what is often thought to be

If there is a concept that has gained awareness during the financial crisis of 2008/2009, it is certainly the concept of risk and its consequence in risk management. The failure of many financial institutions to grasp the risks they were taking appeared so clearly and was so costly that the subject became central both with the regulators and more generally within society. Even though risk is an old concept, its perception has changed over the ages. In this century, the increase of wealth and the advances of scientific techniques may give the illusion to mankind that it has full power over Nature. People are either risk adverse or risk prone, without accepting its possible negative consequences, reactions that could be qualified as extreme and silly. Looking at it in a binary way does not help us cope with it. There is indeed little rational behavior when risk is concerned. Instead we should consider its right definition to be able to manage it.

Already in the XVIIIth century, philosophers came to realize that risk could contain two aspects as summarized by the French thinker Etienne Bonnot de Condillac (1714-1780) who qualified risk as "*The chance of incurring a bad outcome, coupled, with the hope, if we escape it, to achieve a good one*." We see here the birth of a notion that will become prevalent in finance and economics during the XXth century. Taking risks is the proper of entrepreneurs, investors or insurance companies. They do it in search of a future good outcome. The proper of risk taking is the hope to produce a surplus either industrial or financial. The stochastic nature of future outcomes have been noticed early, already with the creation of the first mortality table in the XVIIth century and later in finance by the pioneering work of the French mathematician Louis Bachelier at the beginning of the XXth century. However, a proper treatment of this behavior has not been generalized before the second half of the XXth century with the advances of mathematics and economic theory.

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This notion of risk, which is often confused with uncertainty, is inextricably linked to the reasonable hope of a positive outcome. In economics, the seminal work of Frank Knight (1921) laid the foundation for distinguishing risk from uncertainty. He defines “Risk" as the randomness with knowable probabilities (measurable uncertainty), while “Uncertainty" is the randomness with unknowable probabilities (unmeasurable uncertainty). In this sense, risk is measurable and thus manageable, while uncertainty is part of life and has to be accepted as such and managed only on its consequences. The realization that taking risk can produce a return and that it is measurable has given birth to the insurance industry, starting with the first insurance contracts of the Babylonians up to the sophisticated risk modelling tools of modern insurance companies as well as hedge funds or banks. Quantitative Risk Management (QRM) takes its sources in the progress of computers coupled with the advances in mathematics, in particular in probability theory following Kolmogorov, Fisher and others, and with the birth of extreme value theory. Over the years, QRM has reached a level of sophistication unknown even in the recent past. QRM uses complex tools and extrapolation techniques to obtain insights on the probability of rare events and on ways to diversify away the risks, so to be able to manage the consequences of the bad realization of any of them.

To illustrate with a simple example this notion of risk, let us assume that somebody plays dices and must pay 1 every time the dice shows a six. The probability of getting a six is 1/6 since the dice has 6 faces and we assume it is a fair dice. Thus, the expectation of this game is 1/6. Assume now that this person must play six times and he goes to an insurance to buy a policy that would cover this risk. The expectation of losing after six throws is six times 1/6, thus it is 1. Some simple mathematics (see Busse et al., 2013) show that, for such a policy, the probability of losing more than the expectation is slightly above 26%. This means that an insurer who would require its customer to pay for this policy the expected loss runs the risk of having to pay more than the expectation 1 over 4 times. Indeed, the risk is defined in risk theory as the deviation to expectation. The risk is the unexpected and can be measured by various quantities like the variance or other risk measures. We see here, how one can express in simple terms the risk, once it can be described by a probability distribution. We chose the example of a dice because its mathematics is simple and well known. Clearly, the estimation can be much more complex in a real life problem. However, the principles are the same.

Until now, we have not discussed a fundamental aspect of risk management. It lies in the discovery that risks, when put together and seen as the outcome of a sum, diminishes due to the law of large numbers. If risks are independent and following the same probability distribution, it is possible to reduce almost to zero the risk of their sum. This is called in the jargon of risk managers: “diversification benefit”. Such diversification is the basis of insurance and investment management. The whole portfolio theory developed by Harry Markowitz (1952) is based on this principle: investing in many assets, which are not very correlated, reduces the risk of the portfolio and an optimal portfolio between risk and return can be found. One limitation to diversification comes from the existence of dependence between the risks that constitute the portfolio. The more the risks depend on each other, the less diversification benefit. It is the main problem of insurers and reinsurers. Evaluating the diversification benefit is at the center of QRM.

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2. A stochastic world, with extreme risks

In the last decades, peak risks for insurances and financial institutions have increased. A seemingly paradoxical situation when considering that individual lives in our rich countries are much safer than in the past, but insurance risks have become more important. Affluent societies tend to be more insured and have obviously more to lose. Better living standards imply more demanding customers, backed by the evolution of legal systems to protect them. There are other objective facts that concur to this. The first and most important one is the concentration of population in hazardous areas. The urbanization of the World has gone very far. If the proportion of urban population in the early 50's represented only 30% of the total World population, it became more than 54% in 2014, and is still increasing (see UNO, 2014). In Figure 1, we have displayed the evolution of the World urban population as provided in the UNO World population prospects from 2011. It is not difficult to understand that a natural catastrophe hitting such highly populated areas would have big economic consequences and big insurance claims.

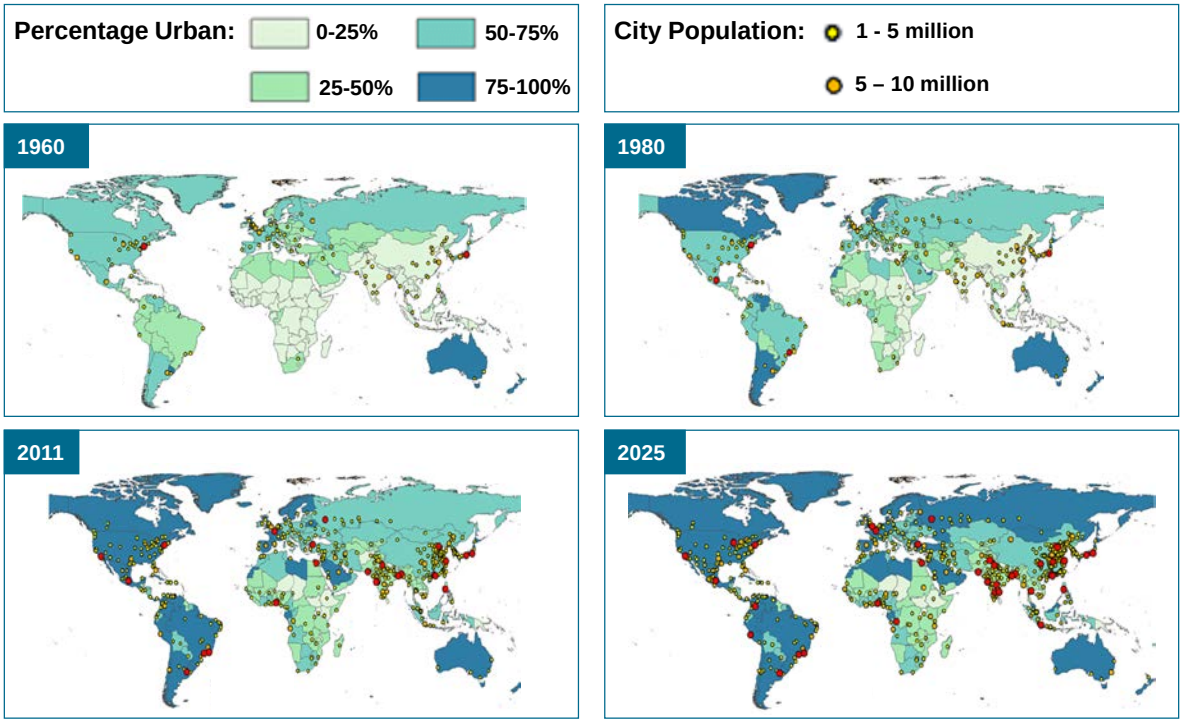

Figure 1 Urbanization trend as measured by the UNO World population prospects of 2011

At the same time, the mobility of people has grown to unprecedented levels. During the eruption of the Islandic volcano Eyjafjöll, Europeans realized that a standstill of the airplanes meant that millions of people were suddenly stranded. In one day 17'000 out of 22'000 flights were cancelled in the whole Europe. For example, in Switzerland alone, there were more than 150'000 people unable to leave the country in one day, which means that more than 2% of a population of 7 million would travel every day by plane! Such links will propagate any big tension, either due to natural or man-made catastrophes, in a matter of hours or days and thus increase the severity of losses. Political instabilities in strategic regions like the Middle East with its oil rich provinces can create shocks that propagate through the whole World Economy as the invasion of Kuwait did in the early 90's.

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Nowadays, the ascension of the Islamic State (IS) poses a threat to the World stability. Its continuous expansion in Iraq, Syria and now also Libya and Nigeria, makes undoubtedly the World less safe. Such terrorism has given birth to an international coalition to fight against it, but also has convinced young islamists, unable to integrate in our modern societies, to fight with IS, bringing the danger within the Western countries. Undoubtedly, risk management has to account for these instabilities and address the issue of potentially very high losses due to them. Imagine a successful terrorist attack on a nuclear power plant in a Western country.

Related to this shift in the population landscape, the increase in wealth and the political instabilities, there is an increase in the interconnectedness between developed countries. The flows of capital create links that free floating foreign-exchange rates, even accentuate through their fluctuations. During the crisis of 2008/2009, the stand still of the interbank money market brought the whole financial system on the verge of collapse. At the same time, the spreading out of structured products has increased the vulnerability of banks to aggregate risks as we are going to explain below. Very few people know that, just before the crisis, 85% of bank assets were held in securitized form, mostly senior tranches[1] of structured products. These senior tranches rely on the protection by the junior tranche, in order to reduce their risk of default. This protection is based on the law of large numbers, so the probability of many bad events happening together is reduced, since the defaults expectation is usually small. Unfortunately, this law applies only during quiet market conditions. When crisis erupts, the law of large numbers no longer holds and those senior tranches act like amplifiers of big market movements (see Dacorogna 2015 for a numerical illustration of this point).

Another factor that contributes to the changing risk landscape is the continuous increase in life expectancy. Today people in developed countries leave 13 to 30 years longer on average, than at the end of the Second World War, when the pension systems have been generalized (see Table 1). Since then, the age of retirement has hardly changed. The increased longevity puts very strong demands on pension funds that have to finance on average twenty years of retirement based on forty years of working activity. At the same time, woman fertility has decreased in Europe, Japan and more and more in China, to levels lower than the replacement rate (2.1 in developed countries and 2.5 for the whole World), inducing an ageing of the population. Both factors contribute to put heavy strains on the retirement systems. Efficiency gains in productivity have partly compensated for these effects but, in the last two decades, the gains have leveled off and we only see small increases of efficiency. Thus the demands on the financing system keep increasing, while interest rates are falling continuously since thirty years. These phenomena contribute to the increasing of the risk landscape. Even if the latter are not directly increasing extreme risks, it rather forces investment managers to take more risks for achieving the returns they need to have in order to finance their portfolios of retirees. Thus they are indirectly increasing the risk of extreme volatility on the financial markets.

[1] The structured products divide the risk of a portfolio of debts into tranches, with an increasing number of defaults in each tranche, when going from junior to senior.

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Table 1 Average Life Expectancy (males and females) from the end of the war till now (Source HMD) and fertility rates (source HFD[2]). The replacement fertility rate is 2.1 per woman in developed countries (in purple the fertility rates below the replacement rate)

Countries	Life Expectancy in 1945	Life Expectancy in 2010	Difference
USA			
Life Expectancy	65.58	78.83	*13.25*
Total Fertility Rate	2.380	1.929	*-19%*
United Kingdom			
Life Expectancy	65.75	80.41	*14.66*
Total Fertility Rate[+]	2.033	1.939	*-5%*
Japan*			
Life Expectancy	51.72	83.00	*31.28*
Total Fertility Rate	4.566	1.379	*-70%*
France			
Life Expectancy	54.94	81.44	*26.50*
Total Fertility Rate[^]	2.997	2.014	*-33%*
Italy*			
Life Expectancy	54.87	81.83	*26.96*
Total Fertility Rate	2.45	1.32	*-46%*
Sweden			
Life Expectancy	68.32	81.52	*13.20*
Total Fertility Rate	2.585	1.987	*-23%*

[+]) Only England and Wales *) Japan starts in 1947 and Italy has data for life expectancy only until 2009 [^]) France starting in 1946

The first years of the XXI[st] century have only reinforced the feeling of living in a World where extreme events happen more often and hit ever more strongly our societies. This is not to say that we did not experience, in the past, large catastrophes. It is even the contrary. Without going back to the big pest plague in the XIV[th] century that killed a third of the whole European population, we can recall the huge volcanic eruption in 1815, just 200 years ago, of the Indonesian volcano Tambora, which was the largest eruption recorded in history. It caused global climate anomalies that included the phenomenon known as "volcanic winter". The year 1816 became known as the "Year Without a Summer" because of the effect on North American and European weather. Crops failed and livestock died in much of the Northern Hemisphere, resulting in the worst famine of the XIXth century, more than 200'000 people are said to have died because of it. Clearly, mankind has gone through vast catastrophes, it is more our perception that has changed, as well as our demand for protection.

[2] Data provided by the Human Fertility Database. Max Planck Institute for Demographic Research (Germany) and Vienna Institute of Demography (Austria). Available at www.humanfertility.org (data downloaded on [22.07.2015]).

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3. Managing risk, a societal demand

A few centuries ago, people's lives were very uncertain. This fragility laid people to have a strong sense of vulnerability. Religion was there to remind people that "paradise was not on this world". Wars, diseases, strong eruptions of random violence were constantly recurring. This environment depressed the willingness to take risks, although many of these risks were measurable in the sense of Knight. The consequence of this general attitude was a slow growth of the economy that characterizes most of the Middle Age and the Renaissance time. The advent of industrialization, combined with the philosophical critic of religion, were strong causes for the change of perception. As a consequence, people have been willing to take more risks and to invest in new ideas. The late XVIIIth and the XIXth centuries have experienced a phenomenal economic growth and social changes. Faith in Science and progress were the philosophical marks of this period. The famous Austrian writer Stefan Zweig expressed this very clearly at the beginning of his last book written in 1941, *the World of Yesterday* (Zweig, 1942): "In its liberal idealism, the nineteenth century was honestly convinced that it was on the direct and infallible road to the best of all possible worlds. The people of the time scornfully looked down on earlier epochs with their wars, famines and revolutions as periods when mankind had not yet come of age and was insufficiently enlightened. Now, however, it was a mere matter of decades before they finally saw an end to evil and violence, and in those days this faith in uninterrupted, inexorable `progress' truly had the force of a religion. People believed in `progress' more than in the Bible, and its gospel message seemed incontestably proven by the new miracles of science and technology that were revealed daily."

By the late XXth century, individual existences in developed countries appeared to be boringly secure by contrast. Epidemic diseases seem under control, society was, by enlarge, peaceful and war between great powers seemed impossible. At the same time, the development of weapons of mass destruction and the terrible episodes of the two World Wars, the environmental problems have enlarged the skepticism towards science and progress. It is not surprising that perception of risk has once more dramatically changed over the course of this economic development. Managing risks helps us to lead more predictable lives. Such enhanced predictability is an essential element in allowing the establishment of ever more complex social and financial interactions, involving more people, across longer distances, and with new and innovative technologies. Society as a whole, demands a world where the vulnerability of mankind is diminished. In the old days, when a natural catastrophe happened, preachers asked people to repent and were pointing to God's anger with men's behavior. Today, we rather look for responsibilities of people who have let the disaster happen without preparing enough for it. The sentiment, that technology has given mankind power over Nature, makes people refusing the consequences of natural catastrophes.

Governments are made liable for the mishandling of floods or earthquakes. Surely, our societies are much more able to prevent the worst consequences of earthquakes for instance by imposing anti-seismic measures to the building industries. We have seen earthquakes up to 6 on the Richter scale causing little damages in San Francisco while being devastating in poorer regions of the globe like Afghanistan or Iran. In the Netherlands, men have built an impressive web of dams to prevent flooding since the big flood of 1952. However, the forces of Nature will never be eliminated and we start to realize this, more and more, with all the debates about climate changes and the

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anthropomorphic nature of these changes. In every modern State, there is an administration in charge of fighting against catastrophes. In every big company, there is a risk management department.

Nowadays, public opinion in democratic countries is not opposed of sending troops abroad to fight, but the majority is not willing to see casualties and deaths coming from these conflicts. This attitude, of course, reduces the efficiency of warfare and pushes democratic governments to build lethal weapons like drones that can fight with minimal human casualties or favor air strikes. Unfortunately, a war can never be won only with airplanes. Troupes on the ground are the only way to complete a task of international police, but this necessarily means losses of human lives. Similarly, people build houses on seashores exposed to hurricanes or in valleys exposed to avalanches, but are not ready to pay high insurance premia for it. This implies a phenomenon of nationalization of insurance risks. For instance, in the US 90% of the flood insurance is retained by the government (see Michel-Kerjan and Kunreuther 2011). Where the market is not present, the State replaces it at a higher cost and we assist at a transfer of costs from the more risky customers to those who are less risky ... In reality, what is at stake here, is the well-being of vast amount of population. Refusing to pay the price of risk seems to have been also one of the causes of the last financial crisis. Rating agencies were giving the highest AAA-rating to structured products based on sub-prime loans of very doubtful credit worthiness. At the same time, CEO's of big banks like Deutschebank were putting their profit objectives at 25% Return-on-Equity (RoE), which can only be reached by taking enormous risks. Every first year student in a finance program is taught that there is no return that is not linked to risk and that returns are commensurate to the underlying risk. Nevertheless, bank analysts let Joe Ackerman (CEO of Deutschbank from 2006 to 2012) set such an ambitious ROE target without questioning him about the risk he intended to take for reaching it. Is it realistic for the largest bank in Germany to try to capture such an amount of profit from an economy that has grown over the past two centuries at a pace of 1.75% per annum? Such large profits have only been seen for startup companies bringing new products on the market, like Apple with the Mac or the IPhone and these abnormal profits were produced only for a little while. Any customer entering a Deutschebank subsidiary will notice that it does not reign there a startup atmosphere! All of these, demand better awareness about risk management and realistic prices for risks. It is the only way society can become more effective in properly allocating its limited resources. It is the subject of our next section.

4. Risk management is not risk avoiding but making society more resilient

The role of risk management is more and more to increase awareness about the dangers, but not to make people more risk averse, and to impede people of doing business. In financial institutions, its role becomes to help optimize the risk/return profile of the portfolio. In other words, to obtain a maximum profit for the risk the firm is taking or, for a given profit expectation, to minimize the risk. This approach to risk is at the basis of an efficient financial system and should in the next years prevail against the older idea of risk management as a guard against risk, or the crazy idea about taking much risk to make very short term profit without measuring its impact. In industry, the role of the chief risk officer is to make it possible for the company to explore new avenues for development while maintaining the business within safe boundaries and making sure that the new products are well in accordance to the safety standards. Hence, there is a strong need for developing adequate

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and relevant tools to model the risks we are facing. The new trend in banking and insurance regulations is to demand that companies have a good quantitative perception of the risks they are taking either through their own internal model or through the use of the models provided by regulators.

Among financial institutions, insurances have, very early on, been one of the vehicles of socialization of risks. Through insurance, people affected by a bad outcome are compensated by those who could escape it. Insurances alongside with governmental actions are the main actors in this important field for society. It thus makes sense to ask them to quantify the risks they have in their portfolio to ensure the viability of their protection. The new regulation is a strong incentive for companies to manage their business based on the risk they take, instead of managing it through cash flows and accounting as it was the case in the past. Risk management becomes central to the business and pushes companies to come up with innovative solutions for covering the risk of their customers. The reinsurers[3] particularly play this role as they have traditionally been those who advise direct insurers on their risks. The latter are more focused in the distribution of their products and the claims management. Much bad has been said about derivative products in the financial system, they play however an essential role in managing risks for investment portfolio. Similarly, insurance products can be considered as ways of hedging the risks. Luckily, and contrary to derivative products, they have not been used until now as instruments for speculation. Although the development of bonds linked to catastrophic events could, on the long run, also become a target for speculators. In any case, the widening of the market coupled with the introduction of risk-based regulation constitutes a new challenge to insurances that have to cope with the ever stronger societal demand for security and coverage.

Similarly, we cannot avoid natural catastrophes, and we already mentioned that their consequences are bound to be more severe due to the evolution of our societies. The role of risk management is then to minimize the consequences of such bad outcomes, putting in place prevention measures like anti-seismic constructions, big dams, early warning systems and so on … An example of these is a set of satellites that are being launched to monitor the oceans, for providing early warnings in case of tsunamis. All this means technological developments and organizational changes to cope with the challenges ahead. Contrary to certain, we believe risk management is fostering development of new technologies and innovative solutions to solve the problems at hand. New technologies must be analyzed for the risks they could generate in order to minimize the impact of those risks by improving the quality and the safety of the products. That is why we see the growing importance of the Chief Risk Officer (CRO) role in the organization not only in financial but also in industrial companies, where it is not uncommon to find strong risk management department, although probably still less quantitative oriented than those of financial institutions, but there too the situation is evolving rapidly towards more quantification of the risks. In every company though, the CRO is not here to forbid the use of new systems, but quite the contrary to foster efficient use of the capital.

[3] Reinsurance companies specialize in selling insurance coverages to primary insurance companies. They help insurances to diversify their risks by unloading some of them onto the reinsurer. They are not directly involved with private customers. Their business model is business to business.

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The societal debate around risk has only started and needs to deepen if risk management is to become a driver to efficiency rather than a way to avoid risk, which is anyway impossible. Society becomes more mature if it understands that taking risk is an essential constituent of progress and innovation. Risk management should help us choose between the risks presenting the best risk/return profile and cope with its inevitable bad consequences.

5. Risk and complexity

We have talked about the change in perception about risk. There are other phenomena that contribute to make risks more complex and difficult to handle. The first one is linked to the change in time scale and the second to increasing dependences. With the globalization and Internet communication, the economic development has become more global, leading to multiple networks. These networks are working at a faster pace than what it used to be, with links at different layers. The relevant time scale is now much faster; what took earlier months even years, takes now hours or days. Due to the degree of complexity, it may be difficult to perceive or to understand a priori for human beings the most important dependences. Human brain might be overrun by the technological breakthrough it created, because of the new time scale. Interactions, consequences of politics in various countries or of different managements in companies, most probably existed in the past, but at the human scale, it was difficult to see or live through their consequences; only historians and scientists could study them based on historical data. At the same time, this acceleration gives us many cases to study and to learn from, allowing us to gain a wealth of experience in little time. With the worldwide immediate communication, everybody knows immediately about any catastrophe, natural or man-made, occurring anywhere in the world, giving the feeling to people that the occurrences of extreme events increase. We also learn soon after the occurrence of such catastrophes about their (possible) bad impacts at the world scale and human time scale, experiencing then the realization of bad outcomes coming from risks.

This century will most probably be considered as a transition phase, where mankind made fantastic jumps forward, but was also often overwhelmed by its own new technological advances and fast tools. On one hand, we are not able to follow their fast pace and we find ourselves more as serving those tools rather than being helped by them. On the other hand, we can regard this as a challenge to be able to master the technological breakthrough and to use it as a helping toolkit to expand our reach rather than suffering from it. There are two points that can emerge from this situation. The first is related to the fact that we live many outcomes of risks during our lifetime. This might give us the opportunity to study them better, since we can often see their immediate consequences and observe *in vivo* their interactions. Once again, some of these interactions have been generated by our new framework, but some others might already have existed in the past. Yet, people were less aware of them because it took a longer time to observe them, not within one generation. Second, the appearance of new interactions could help us changing our views on phenomena in order to master their consequences. The conservatism of trying to read or fit phenomena within a given theoretical frame, a given economic theory, will have to be replaced by a more scientific approach, learning from observations that are becoming more and more widely available, rather than selecting them a priori to fit within a theory.

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The existence of complex interactions and phenomena does not imply that the model to handle them should be itself complex. The scientific approach consists in distinguishing the main contributions to the phenomenon and in modelling these main contributions. Fundamentally, science helps simplifying without reducing the problem, putting it on grounds that can be treated and experimentally proven. Such an approach will be crucial to handle this complex world, with inherent (always existing along the time) risks and new ones born from more connections. Studying the dependence between risks is essential for understanding their real impacts and consequences. This has always been a topic in probability and statistics when looking at what is called a multivariate framework. Notions like linear correlation or copula, for instance, were introduced to treat this problem. The first one was formalized mathematically by Karl Pearson in a paper dating back to 1895 in the context of biometric studies[4]. The second was first formalized by Sklar in 1959 in the context of the probability theory to solve a theoretical problem posed by Fréchet, but turned out to become an important tool for applied probability and the evaluation of risks of insurance and reinsurance. The realization that risks are more dependent in extreme situations led to the development of the notion of systemic risks, risks that would affect the entire system as well as the notion of systematic risks, *i.e.* components present in all other risks. In the next few years, research in statistics and probability will have to make significant progress in this area if we want to master the risk at an aggregate level. We have seen that social demand goes in this direction of the need for protection at a global level.

During the last financial crisis, reality reminded us that the new quantitative tools must be used with the full knowledge of the assumptions that were used to build them. These assumptions limit in certain ways the application and the validity of those tools. Thus, outmost care has to be exercised in using their results and generalizing their usage. On this subject, a controversy erupted on the use of models in the area of credit risk evaluation particularly for the sub-prime debts. A famous article by Salmon (2009) entitled: "Recipe for Disaster: The Formula That Killed Wall Street" casted doubts on the ability of quants[5] to correctly estimate risks. The author was pointing to the fact that all of those models grossly underestimated the tendency of defaults to be much correlated in extreme situations. People like Nassim Taleb go around the World claiming, in an undifferentiated way, that people have not understood randomness. With the difficulties of implementing the new risk based solvency like Basel II or Solvency, skepticism towards quantitative approaches is spreading. Clearly, as we already wrote, unrealistic expectations and greed led to highly leverage financial institutions, which left them extremely fragile when came the first turbulences. However, we do not believe that the culprits are the models. Many of the models used by banks at that time relied on Gaussian assumptions that grossly underestimate the probability of extreme events. However, there were already other models, based on Extreme Value Theory (EVT) that would attribute reasonable probabilities to what actually happened. Unfortunately, they were badly regarded by management as their usage would have implied higher capital charges and thus less profits for the companies and less bonuses for them. As always during speculative bubbles, the culprit is really greed. This time, it was coupled with the wrong belief that any quantitative models would prevent unrealistic expectations. In the mid-nineties, Alan Greenspan, head of the Federal Reserve at the time, could

[4] He was formalizing the idea proposed by Francis Galton in 1885 in his presidential address to the Anthropological Section of the British Association.

[5] The word, „Quants", is the familiar name given in Wall Street to traders who base their valuation on financial mathematics.

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tell in his opening speech of an international conference held in Washington that the time has come where quantitative tools for risk management will prevent speculative bubbles and financial crises from spilling over the economy. Similar statements on the low probability of failures are often made by safety engineers of nuclear power plants with the consequences we saw in Fukujima for instance. This attitude was rightfully put into question during the crisis or during the Japanese tsunami. Yet, it is as well dangerous to abandon all the progress we experienced in understanding and managing risks because certain attitudes led to the second major financial crisis of the last hundred years or to accidents of the type of Fukujima. Nevertheless, the controversy rages between those who defend a quantitative approach and those who advocate a qualitative approach to risk management. We shall see in the next section that both approach need to be used in order to achieve an efficient management.

6. Do we need more or less science for tackling the complexity of risk?

As for science in general, there is a strong disillusion among practitioners towards the use of quantitative models, even though they have put the work of risk managers on a much more rational and efficient way. The many mistakes that led to the financial crisis have casted doubts on the appropriateness of financial mathematics to adequately assess the risks of financial institutions, and much emphasize is now put on qualitative risk management. The question is thus: should we replace the faith in models by a faith in procedures and guidelines?

Let us first succinctly define the two terms. Qualitative risk management consists into two parts, one descriptive, which concentrates on the taxonomy of risks facing the enterprise. The second one is the development of a corpus of procedures and guidelines to deal with them. Quantitative risk management consists in mathematically modeling the behavior seen in data to be able to deduce future scenarios. Its goal is to go beyond the data to generalize and gain meaningful insights on future behaviors. It is essentially a way to extrapolate from past data. Clearly these definitions show that it is wrong to oppose both approaches. To the contrary, they complement each other. A taxonomy of risks cannot be effective without an understanding and a quantification of their consequences. An extrapolation to possible scenario would be useless without the existence of guidelines and procedures to manage their occurrences.

Historically, risk management was limited to the qualitative approach and it is still often the case in industry. The quantitative approach started to emerge in financial institutions due to the progress made in modelling and understanding risks through statistics and probability. It is the combination of this with numerical analysis profiting from the constant improving of the performance of computers that made it possible to develop mathematical models to assess risk. The first global attempt was made public by JP Morgan when they launched the RiskMetrics methodology to the marketplace in 1992. They made the substantive research and analysis that were requested by the chairman of J.P. Morgan, Sir Dennis Weatherston, to get a daily report quantitatively measuring and explaining the risks of the firm. It is the 1994 RiskMetrics technical document that popularized the concept of Value-at-Risk to measure with one number the risk of a portfolio (Zangari 1996). At the same time Swiss Re the second largest reinsurer embarked in the building of their internal model (James *et al.*, 2013) aiming at modelling both the assets and the liabilities of the company. With the advent of the

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risk based solvency regulation of Basel II and Solvency II, the fortune of QRM has grown up to the point where they have been criticized for not having been able to avoid the financial crisis of 2008/09.

The complexity of interactions we talked about above cannot be apprehended without a good qualitative risk management that explores the many ways various risks relate to each other, while quantitative risk management allows measuring and verifying our good comprehension of the processes at stakes. The real productive way to catch the dynamics of a risk landscape that changes rapidly is to have a constant back and forth from qualitative investigations to quantitative modeling. Limiting risk management to one of these aspects or opposing both is reducing our ability to explore the full complexity of the web of interactions. Limiting ourselves to qualitative assessment condemns us to stay with a fragmented vision of reality and to debates that are similar to the theological debates of the middle age where no direct relation to reality and to experimental proof was deemed necessary. Stopping at the quantitative assessment, condemns as to a static view of the world and to a risk of oversimplification. Relying solely on financial models without understanding their limitations and the extent to which their assumptions work, has proven to be very dangerous during the last crisis.

To better cope with the stochastic world we are living in, we rather need more science than less. We need a science that is conscious of its limitations and tries to push them back as progress emerge. We need a science that relies on both the contributions of the qualitative and the quantitative approaches to keep improving our understanding of an ever changing reality.

7. Conclusion

Living in a rich World subject to large stochastic shocks demands a level of sophistication in the handling of risks that we have not known in the past. At the same time, we need to accept that risk is an inherent component of innovation and progress. The only way to push societies to engage in new adventures is to accept the possibilities of a bad outcome in hope that if it does not materialize we will benefit from it. In turn, we need new tools to apprehend and manage the future outcomes and hedge their worst scenarios. The fast pace at which we experience catastrophic outcomes pushes research to come up with new ideas and theories that will be able to contribute to the prevention and the reduction of the dangers we are facing. Climate changes, political instabilities, over-reliance on complex IT systems, increasing social inequalities in the developed countries are some of the key challenges ahead of us. To help us prepare a better future for the new generations, risk management should be given the aim of improving the efficiency of our work by optimizing risk and return.

The risk management of the future will have to rely on both qualitative risk assessment and quantitative risk modelling. Opposing the two approaches will not solve our problems but deepen them. A rigorous scientific approach coupled with a wide vision of reality and its complexity will be the winning strategy. The future is wide open to good scientists and managers to provide society with both the security it demands without losing the creativity and the entrepreneurship. They are the indispensable ingredients of economic development and prosperity.

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